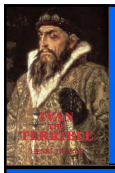
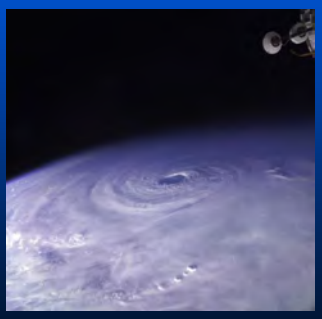
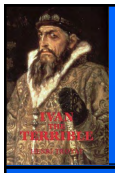


Ivan Metocean Overview

- Focus on deep water for now
- Agenda
  - Ivan Wind/Wave Hindcast
  - Current Hindcast
  - Wave/Wind measurements
  - Historical perspective
  - NWS Wind Forecasting
- Each talk followed by 5-min questions





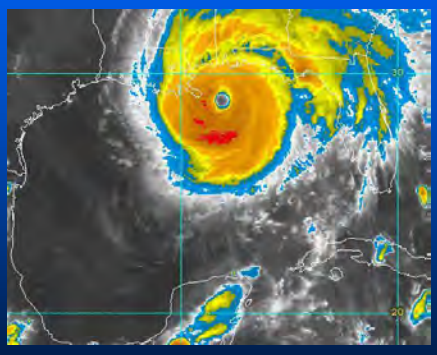
Ivan Characteristics

Ivan…

- Category 3-4 Hurricane
- Central pressure 939 mb
- Radius=20-30 nm
- Max Wave H_{max}~96 ft
- Wind=92 kt (33 ft, 30 min)

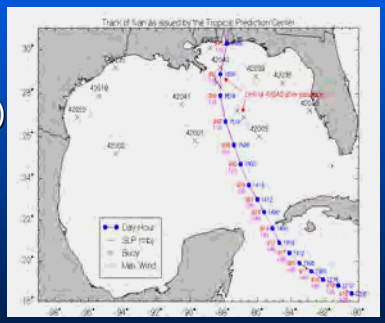
API/RP-2A 100-year…

- d/w H_{max}=71.2 ft
- Wind=87 kt (33 ft, 30 min)

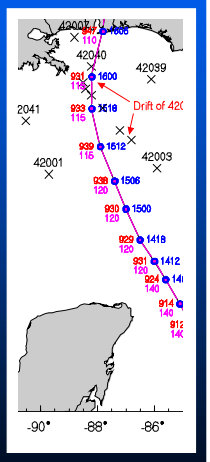


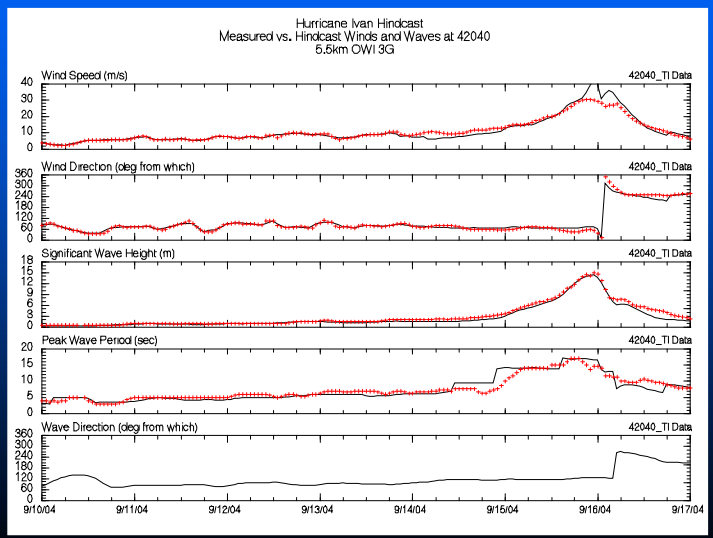
Hindcast Methodology

- Modeling done by OWI
- Basic Steps
  - specify storm parameters (time history of pressure, etc.)
  - Run wind model to determine wind field every 30 minutes
  - Use modeled winds to drive wave & surge models
  - Validate against site measurements

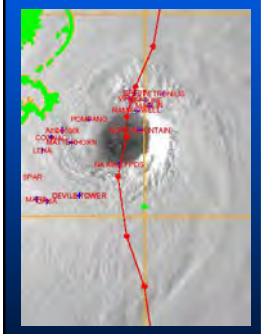


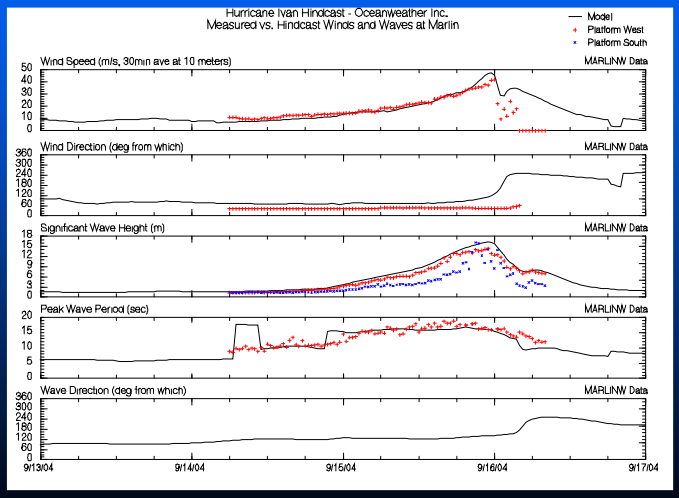
Wind & Wave Comparison NDBC Buoy 42040





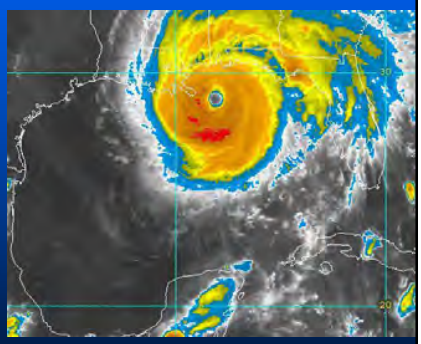
Wind & Wave Comparisons at Marlin TLP

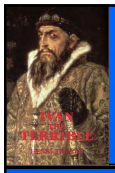




Wave & Wind Hindcast Summary

- Methods & models (Gumshoe) same as used for API RP2A.
- Excellent comparisons with Ivan measurements at buoys & platforms
- Gumshoe model works for Ivan
- H_{max}~96 ft; W_{max}=92 kt (33', 30 min)
- RP2A 100-yr:
  H_{max}=71 ft; W=87 kt (33', 30 min)





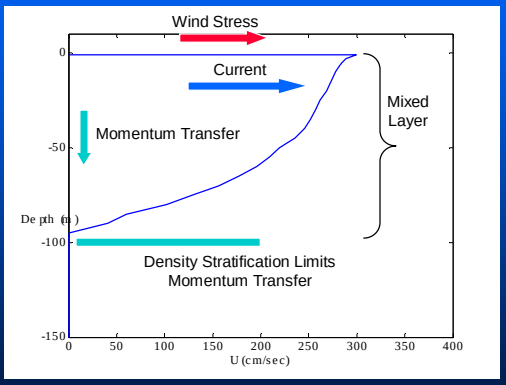
Ivan Current Hindcast

- Review Hurricane Currents
- Hindcast Currents from Ivan
- Design Implications?

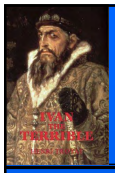
Hurricane Current

Hurricane Current:

- Generated by local wind stress
- Strongest on right side in DW (10's of km wide)
- Current peaks within 1-3 hours of max wind
- Strong inertial component persists 3-4 days

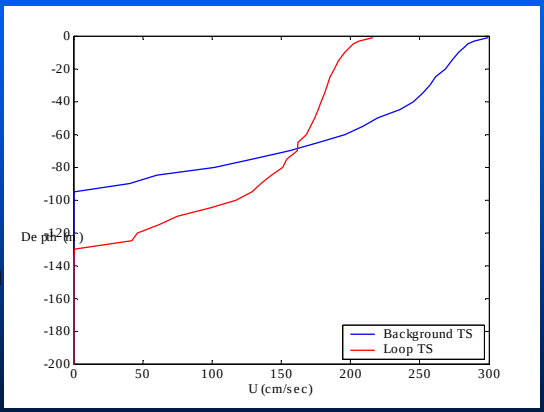


Hurricane Current

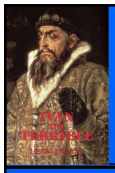


Hurricane-Loop Interaction

- Varying temperature and salinity profile has strong influence on hurricane current
- Joint hurricane-Loop load cases likely important for southern DW areas

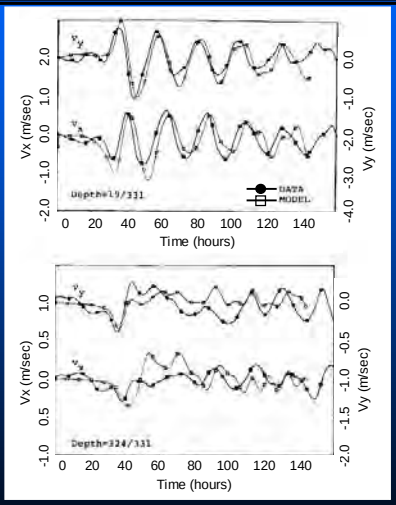


Effect of Different Temperature and Salinity on Hurricane Current profile

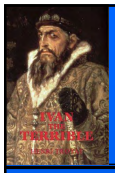


Hindcasting Ability…

- Current hindcast ability not as developed as that for winds, waves
- Little data to compare against, no profile data above 30 m
- Bulk mixed-layer model does good job in 5 of 6 comparisons with ML averages

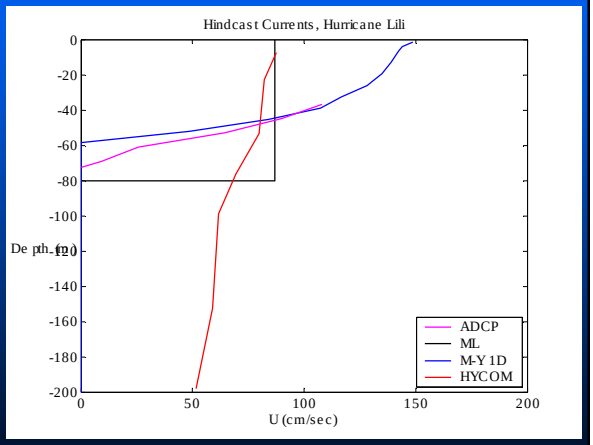


ML Model Compared to Measurements, Hurricane Frederic (Sept. 1979)

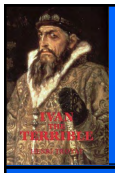


Hindcasting Ability

- Recent data shows substantial shear in mixed layer
- M-Y 1D profile model compares well in DW
- Bathymetry needed around shelf/slope
- Models are very sensitive to inputs

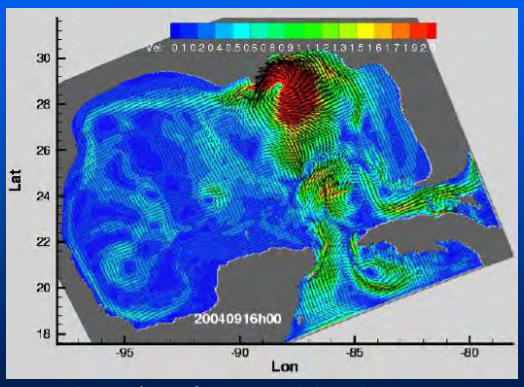


Profiles Near Time of Peak Current Near Genesis

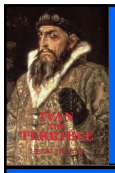


Ivan Hindcasts

- Commercial hindcast available with HYCOM
- Preliminary comparison on slope with Navy data shows reasonable agreement
- Bulk ML, M-Y 1D profile analyses also performed
- No DW current data for validation

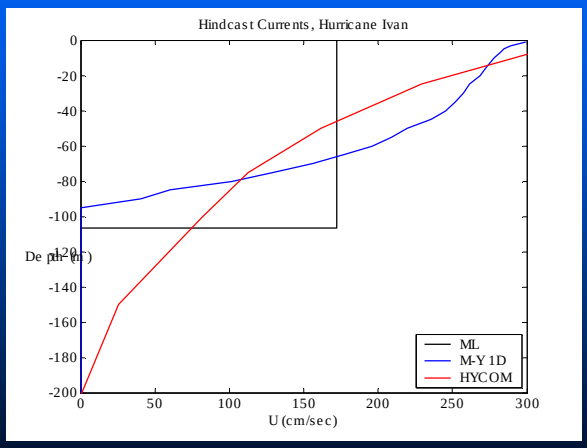


Snapshot of Ivan HYCOM Currents

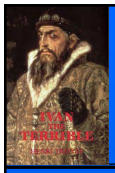


Model Comparisons for Ivan in DW

- Mixed-layer depth and average speed from Bulk ML, M-Y 1D profile models similar
- HYCOM mixed-layer average speed is similar, but profile and ML depth are questionable

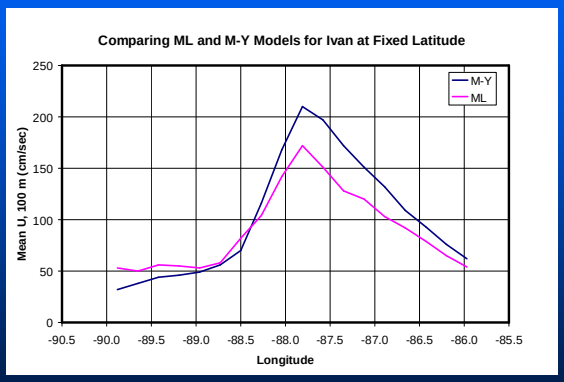


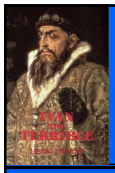
Profiles Near Time of Peak Current in DW



Model Comparisons Continued

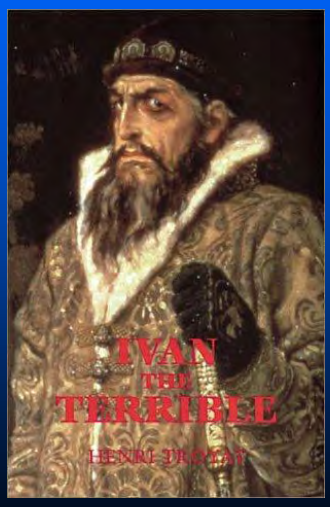
- Bulk ML, M-Y 1D profile model predict similar currents across storm track
- M-Y 1D predicts higher mean speeds on 100 m
- HYCOM result includes Ulysses eddy currents, so not shown





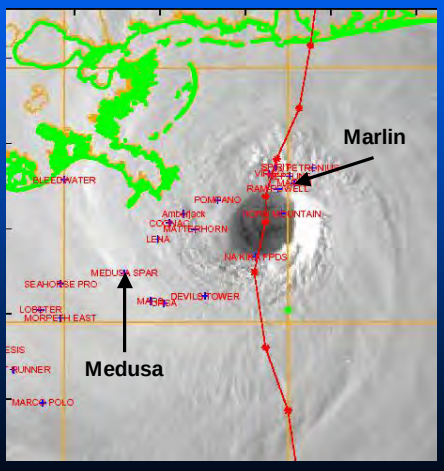
Summary of Currents

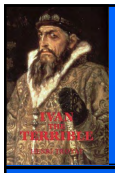
- Ivan model efforts hampered by lack of data for validation
- Bulk ML, M-Y 1D profile models with limited prior validation yield similar results for Ivan in DW
- HYCOM results in DW are questionable – need to investigate
- M-Y 1-D profile model should be used to derive criteria for shallow draft platforms (Bulk ML model suitable for spars)



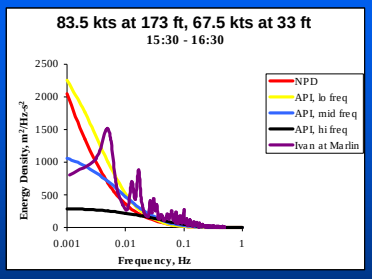
Industry Site Measurements at Marlin and Medusa

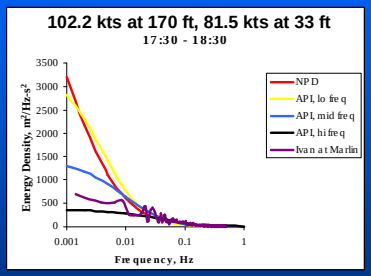
- Marlin TLP
  - Wind at top of crane
  - Wave radars on SE (noisy) & SW sides
  - High sampling rates
- Medusa Spar
  - Wave radars on SE (noisy) & NW sides
  - High sampling rates





Wind Spectrum at Marlin

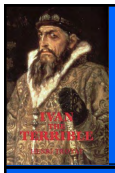




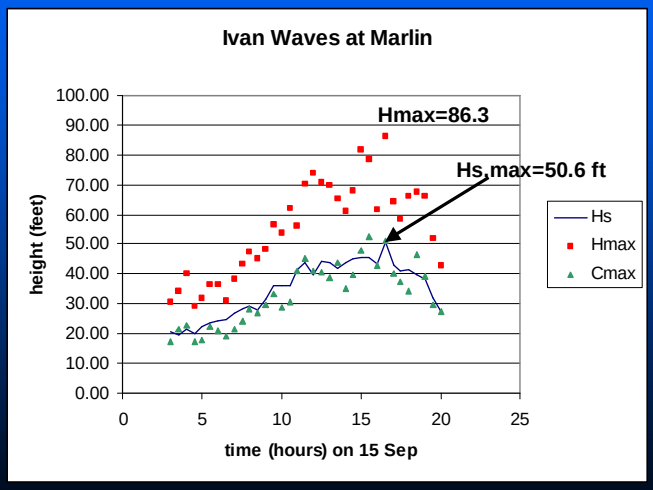
1-sec gust factor = 1.36
1-min gust factor = 1.15

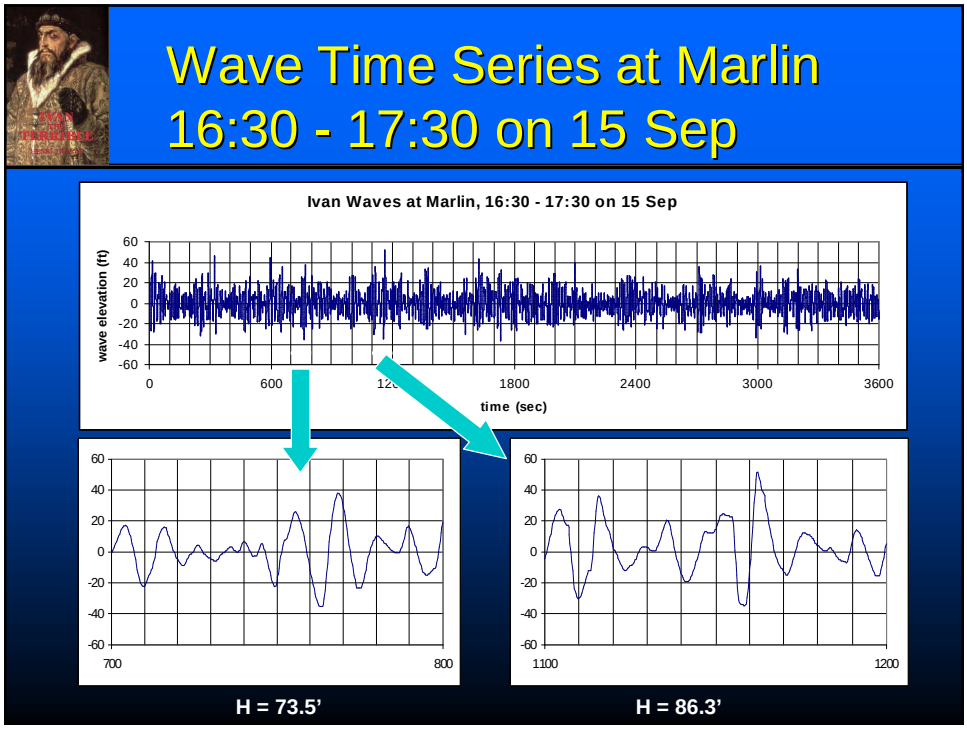
1-sec gust factor = 1.34
1-min gust factor = 1.14

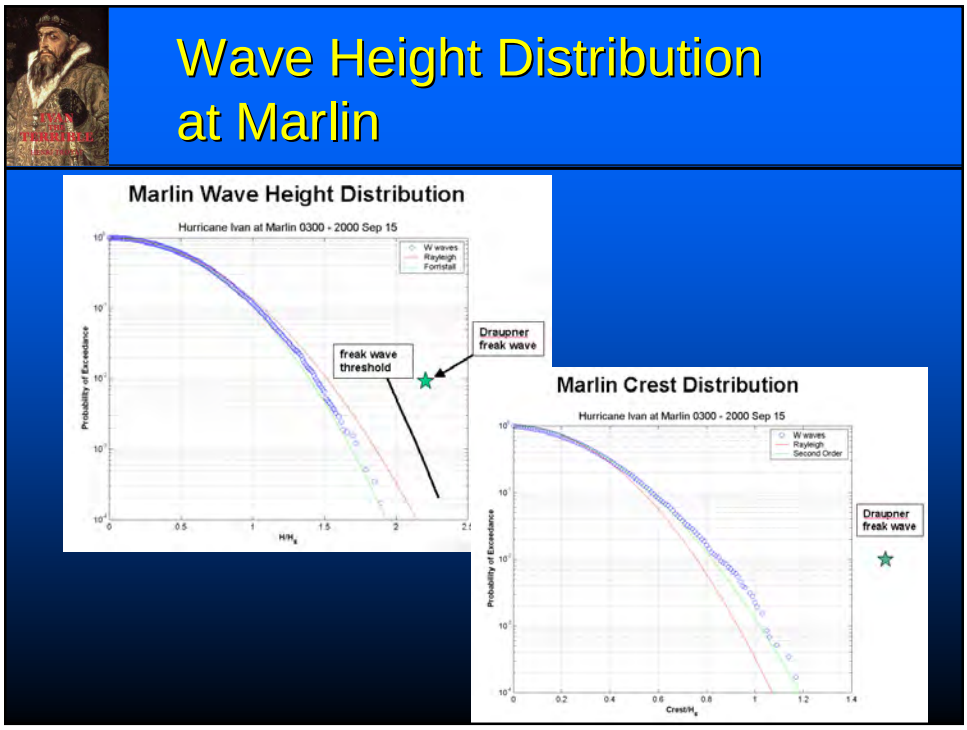
- **Gust factors agree reasonably well with NPD**
- **Earlier spectrum agrees with NPD model but later spectrum is deficient in very low frequency energy**



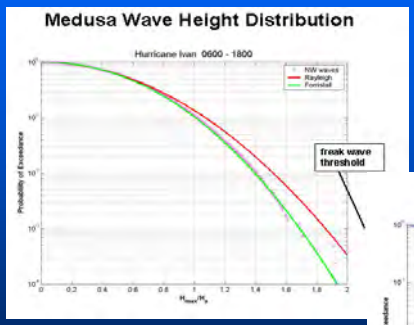
Wave Time Series at Marlin

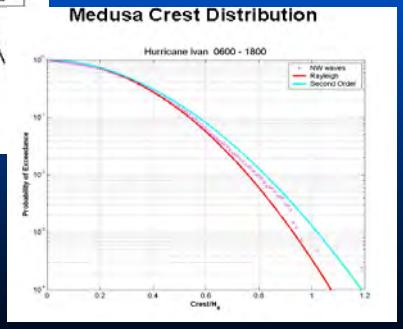



Wave Time Series at Marlin
16:30 - 17:30 on 15 Sep
Ivan Waves at Marlin, 16:30 - 17:30 on 15 Sep
wave elevation (ft)
time (sec)
H = 73.5'
H = 86.3'

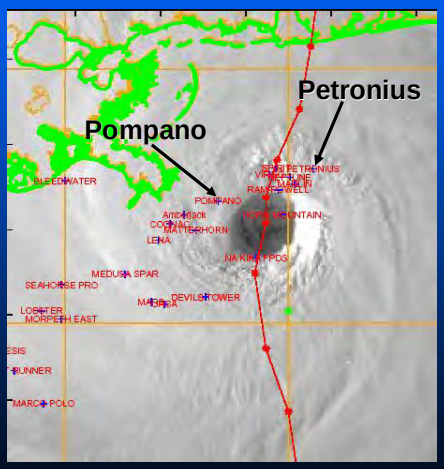

Wave Height Distribution
at Marlin
Marlin Wave Height Distribution
Hurricane Ivan at Marlin 0300 - 2000 Sep 15
freak wave threshold
Draupner freak wave
Marlin Crest Distribution
Hurricane Ivan at Marlin 0300 - 2000 Sep 15
Draupner freak wave

Wave Height Distribution at Medusa





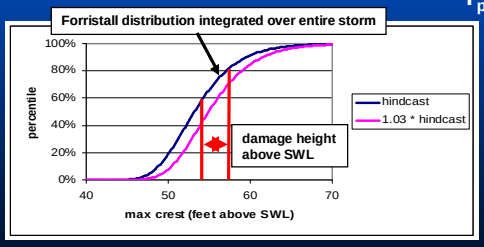
Platform Damage at Petronius and Pompano



Petronius Platform Damage

Damage at 54.1' – 57.4' above storm water level (after accounting for 2.6' storm surge, tide, and setdown)

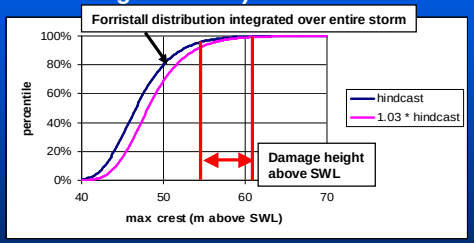
H_s=51.1'
T_p=15.4s



Corresponds to 60th – 80th (40th – 70th) percentile estimate of maximum crest from Ivan hindcast

Pompano Platform Damage

Damage at 54.1' – 61.3' above storm water level (after accounting for 1.6' storm surge and tide)



Corresponds to 95th – 99.9th (90th – 99th) percentile estimate of maximum crest from Ivan hindcast

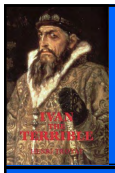
H_s=45.4'
T_p=16.8s

60°

H_s=29.2'
T_p=10.2s

H_s=34.9'
T_p=16.8s

Unlucky? Crossing wave trains?
Wave enhancement by platform?



Wave / Platform Interaction

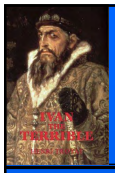
80’ wave at Ekofisk

Model tests

What is the height of the undisturbed wave crest (green water) that might be inferred from local platform damage?

Measurement Summary

- Wind spectra fit standards
- No evidence of “freak” (rogue) waves
- Distributions of measured wave crests fit design standards
- Damage provides no compelling evidence for criteria change



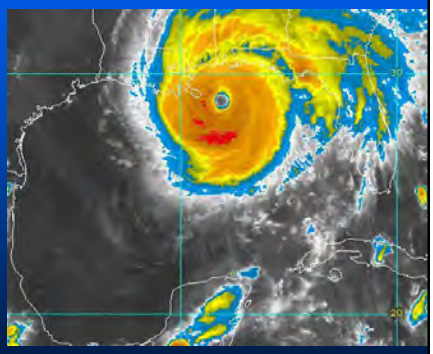
Ivan Characteristics

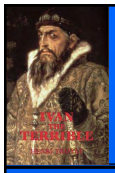
Ivan…

- Pressure 939 mb (93%)
- Radius=25 nm (25%)
- Forward Spd=10 kt (50%)
- Wind=92 kt (33 ft, 30 min)
- Max Wave H_{max}~96 ft

API/RP-2A 100-year…

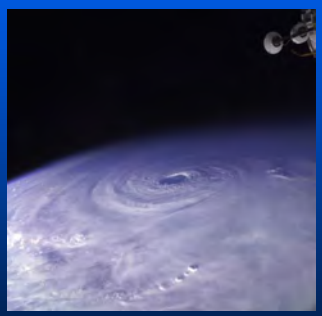
- d/w H_{max}=71.2 ft
- Wind=87 kt (33 ft, 30 min)



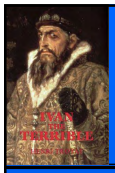


Key Questions

- What return interval was Ivan?
- Was Ivan statistically "unexpected"?
- Should criteria be increased & if so in what part of Gulf?

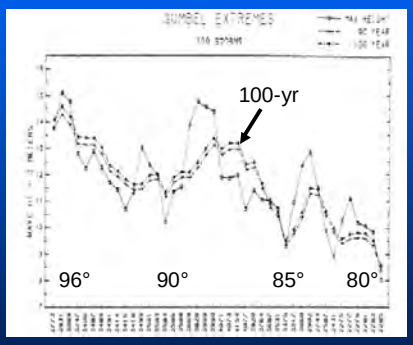


Satellite image of Ivan

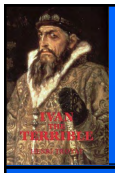


Ivan's Return Interval? Site-to-Site Variability

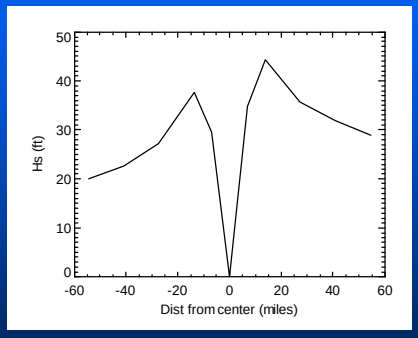
- Model hindcast (GUMSHOE) gives large site-to-site variability
- Causes of variability
  1. Water depth & fetch
  2. Insufficient sample of severe storms
  3. Regional differences



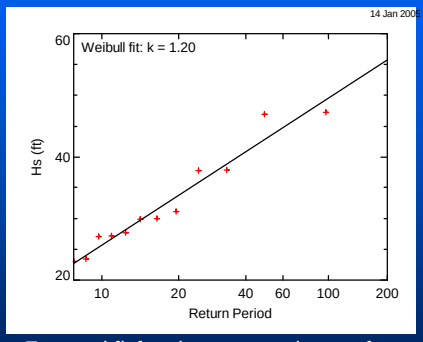
100-yr & max H_s along the 600 ft isobath based on Gumshoe site hindcast



Insufficient Sample of Severe Storms



Parametric model cross-section of the H_s in Hurricane Camille.

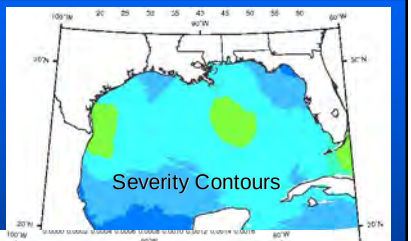


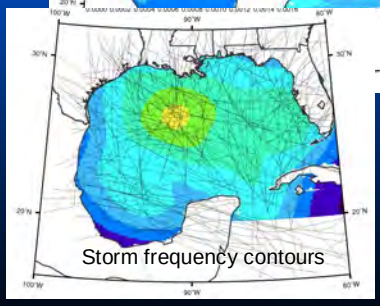
Extremal fit for site near maximum of Camille. W/o Camille, H_{s100} is 4 ft lower.

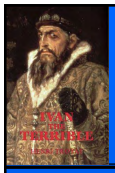
Given small size of storms & infrequent occurrence, we need several hundred years of data to sufficiently reduce this "noise"

Regional Variations

- Recent work suggests real regional variations
  - Severity
  - Frequency
- Possible physical causes
  - Persistent Loop water
  - Gulf geometry
  - Atmospheric influences







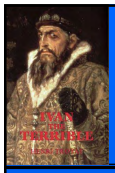
Removing the "Noise"

- 10^{-4} JIP is addressing issue
- Solution 1: combine (pool) sites that are similar but not identical sites
- Solution 2: develop a deductive model

Uncertainty of n-yr Hs

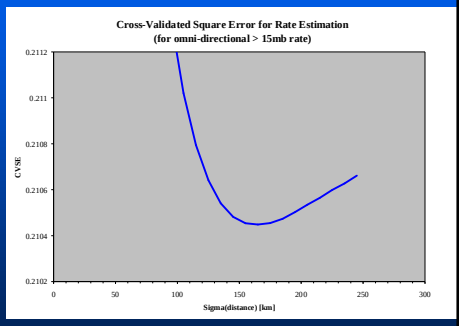
Model	100-yr	10k-yr
Gumbel Site	±2.5'	±5.0'
Gumbel Pooled	±1.6'	±2.0'

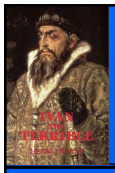
Pooling reduces uncertainty



Choosing the Optimal Pooling Size

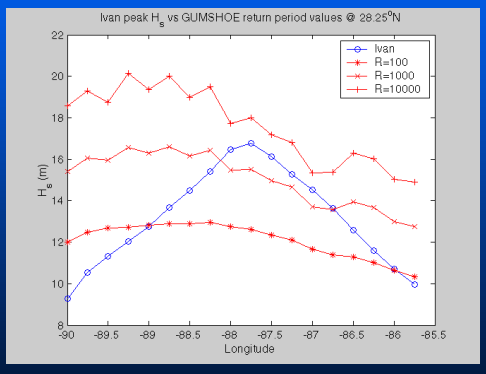
- Apply “cross-validation” (Chouinard,1992, OTC)
- Optimal dist. ~ 100 miles
- 10-4 JIP has found similar results
- Results that follow use pooling at 5-7 sites
- Will also use this 100-mi scale in another key way





What Return Interval Was Ivan?

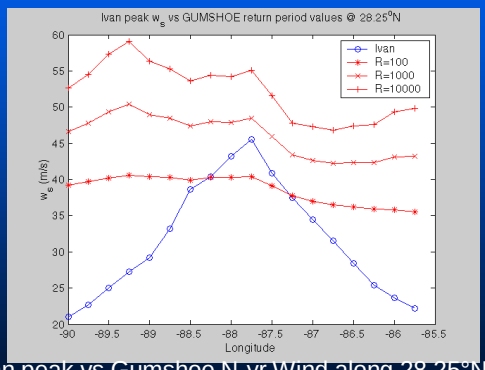
- ~2500 yr H_s at site where peak occurred
- Exceeded H_{s100} over ~150 mile swath



Ivan peak vs Gumshoe N-yr H_s along 28.25°N

How Does Wind Compare?

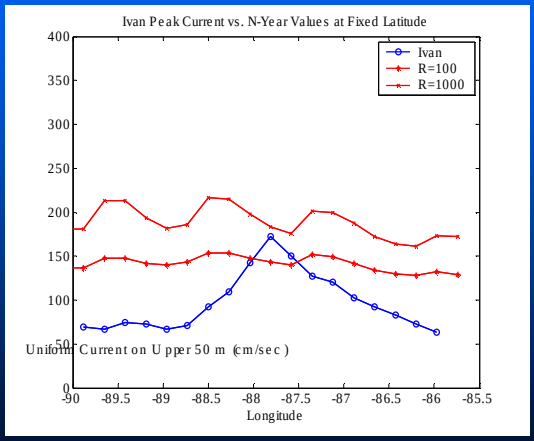
- ~700-yr Wind Spd (33 ft, 30 min)
- Exceeded 100-yr over ~60 mile swath



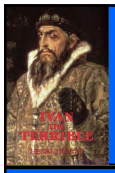
Ivan peak vs Gumshoe N-yr Wind along 28.25°N

How Current Compare?

- ~700-yr 50-m
- Exceeded 100-yr over ~ 20 mi swath
- Storm that causes 100-yr Hs does not usually cause 100-yr wind or current

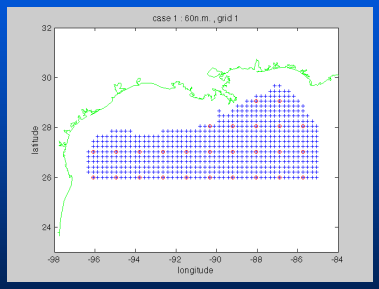


Ivan peak vs N-yr Layered Model along 28.25°N



Was Ivan Statistically Unexpected?

- Intuition: expect one, 100-yr storm in 100 yrs in entire Gulf
- Fact: expect Hs_{100} exceeded somewhere in Gulf every 4 yrs
- Because……
  - Must treat Gulf as statistically independent regions
  - Assume "regions" in Gulf are 100 mi apart
  - Expect a 2500-yr H_s in 100 yrs
  - That sounds like Ivan!

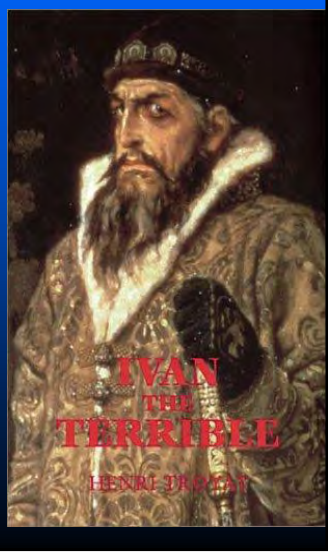


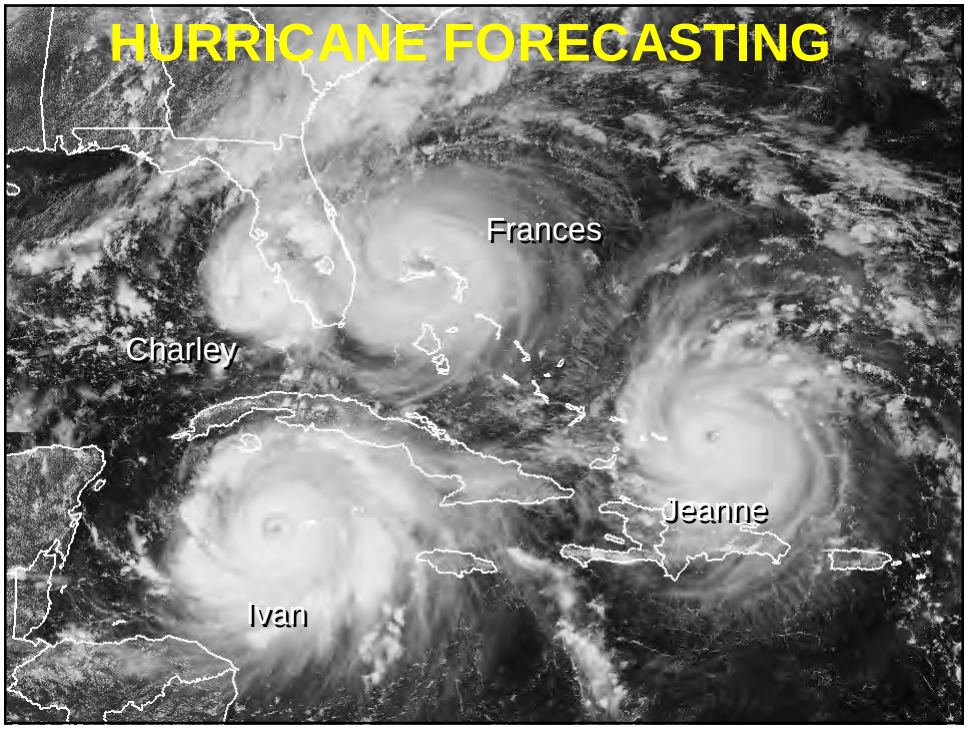
25 sites, ~ 100 mi apart

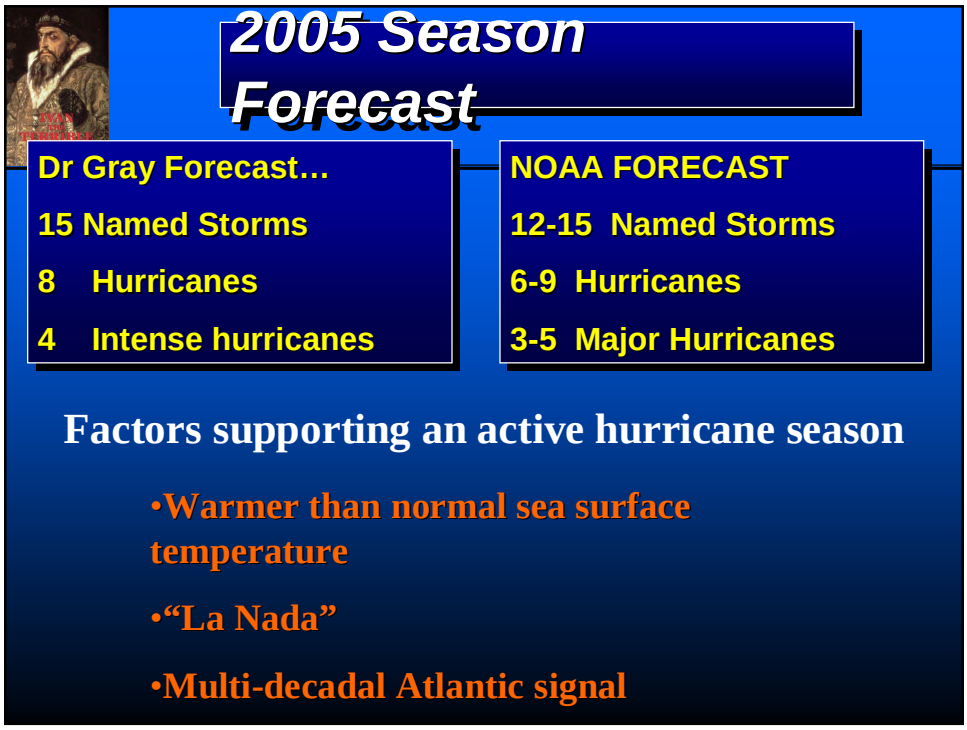
Ivan not a major surprise based on pre-Ivan distribution

Metocean Summary

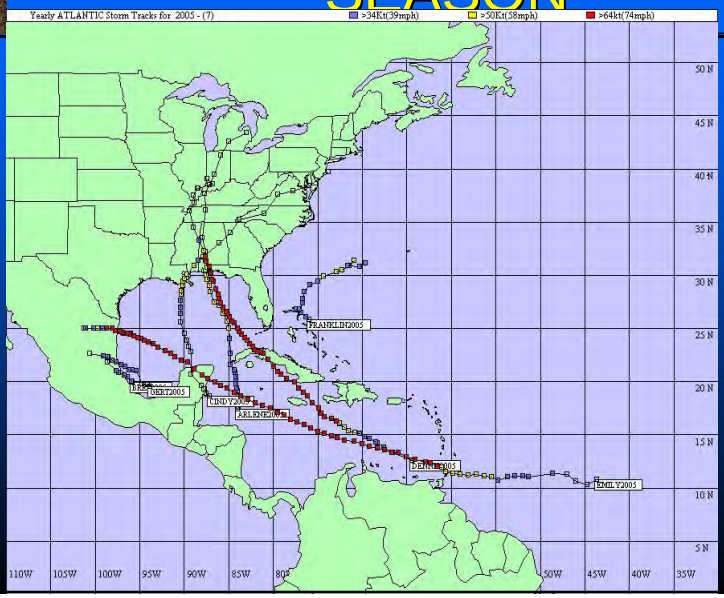
1. Ivan generated peak H_{max}~ 96 ft
2. Highest in 100 yrs but not by much
3. Ivan generated ~2500-yr Hs using the pre-Ivan extremal distribution
4. Ivan peak wind & current ~ 700-yr event
5. Could argue Ivan is an "outlier"
6. But new designs in Eastern Gulf should include Ivan
7. Under peak of Ivan, a d/w facility could have seen wave loads ~30% higher then present design but still << then 100% factor of safety
8. Further work ….
   a. Look at metocean in shallow sites
   b. Review API metocean guidelines
   c. Obtain more upper water-column currents




HURRICANE FORECASTING
Frances
Charley
Jeanne
Ivan

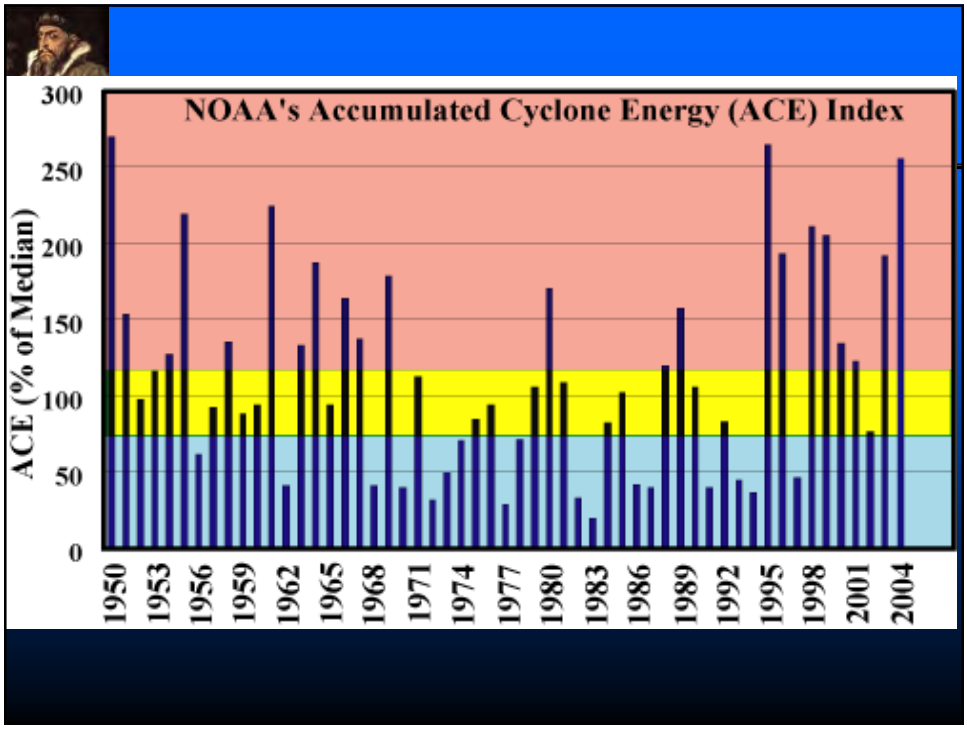

2005 Season Forecast
Dr Gray Forecast…
15 Named Storms
8 Hurricanes
4 Intense hurricanes
NOAA FORECAST
12-15 Named Storms
6-9 Hurricanes
3-5 Major Hurricanes
Factors supporting an active hurricane season
•Warmer than normal sea surface temperature
•"La Nada"
•Multi-decadal Atlantic signal

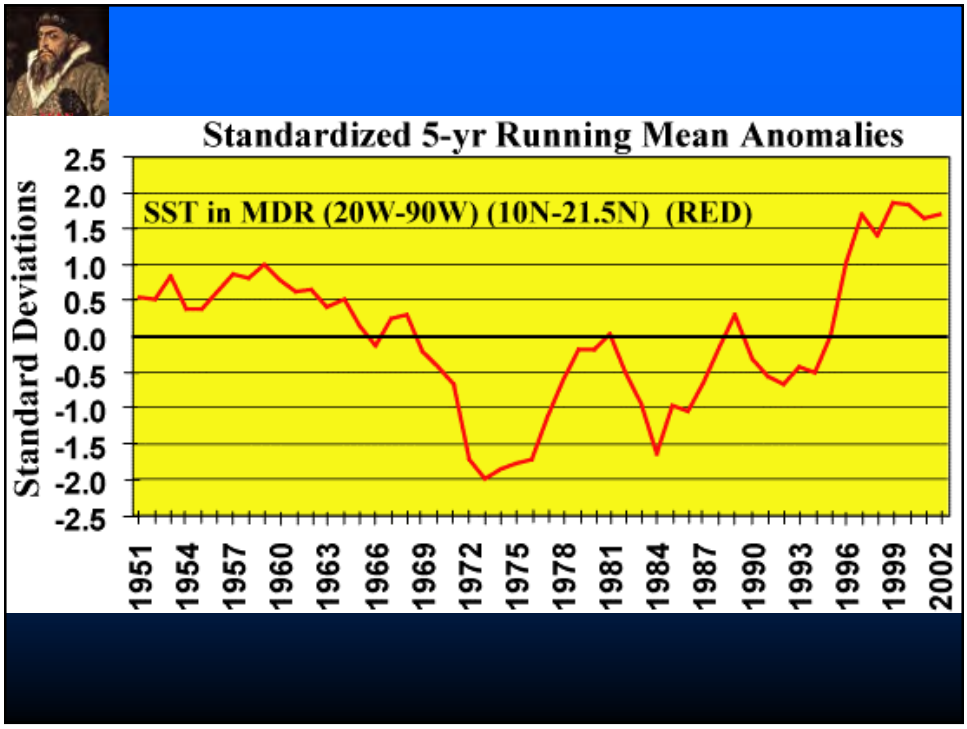
2005 HURRICANE SEASON

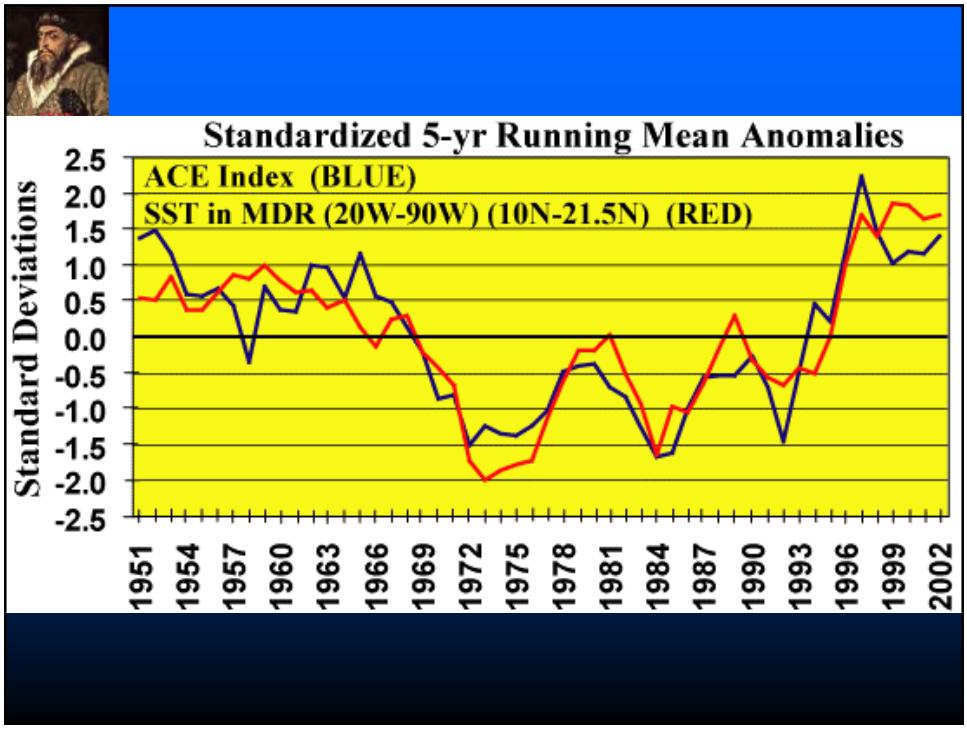


2005 SEASON

- 7 Tropical Storms
- 2 Major Hurricanes (Dennis & Emily)


NOAA's Accumulated Cyclone Energy (ACE) Index
ACE (% of Median)
300
250
200
150
100
50
0
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004


Standardized 5-yr Running Mean Anomalies
SST in MDR (20W-90W) (10N-21.5N) (RED)
Standard Deviations
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002


Standardized 5-yr Running Mean Anomalies
ACE Index (BLUE)
SST in MDR (20W-90W) (10N-21.5N) (RED)
Standard Deviations
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
1951
1954
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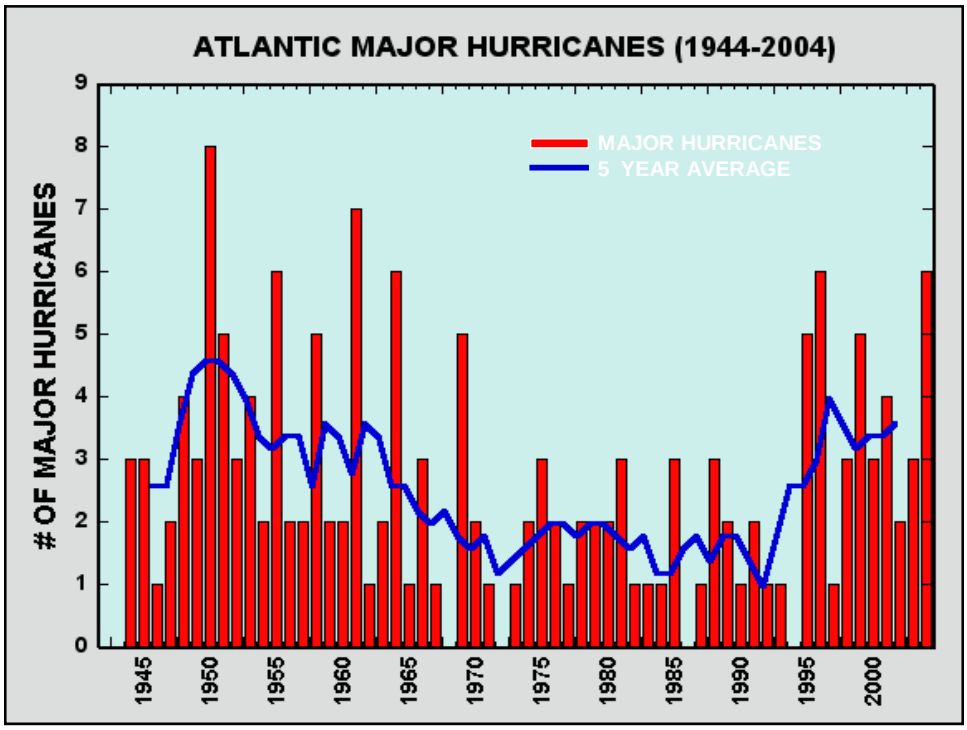
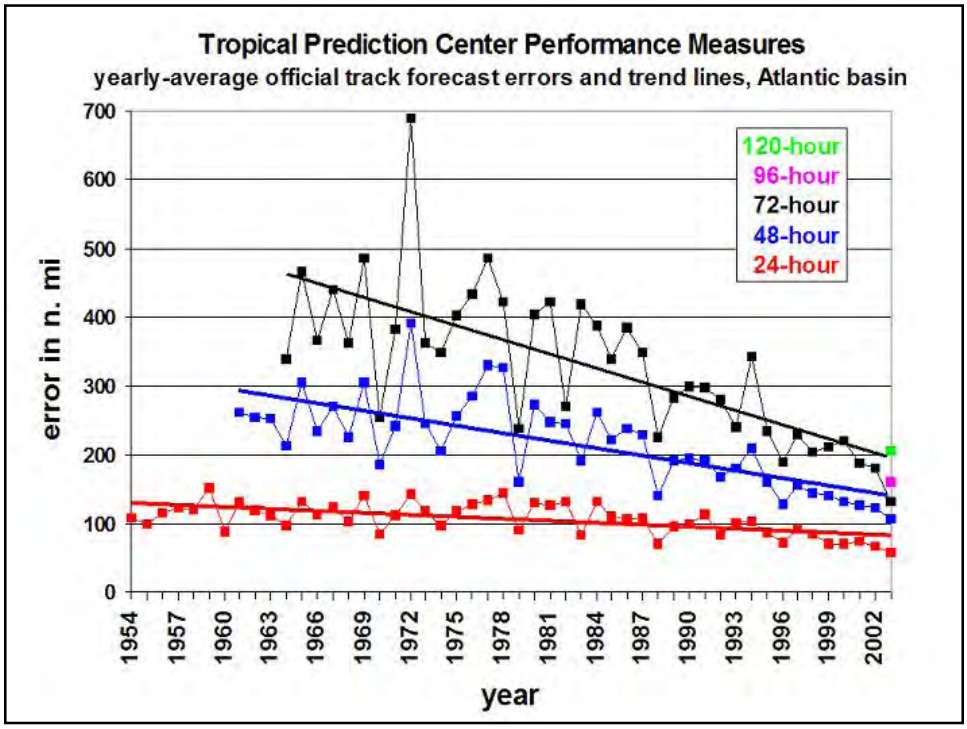
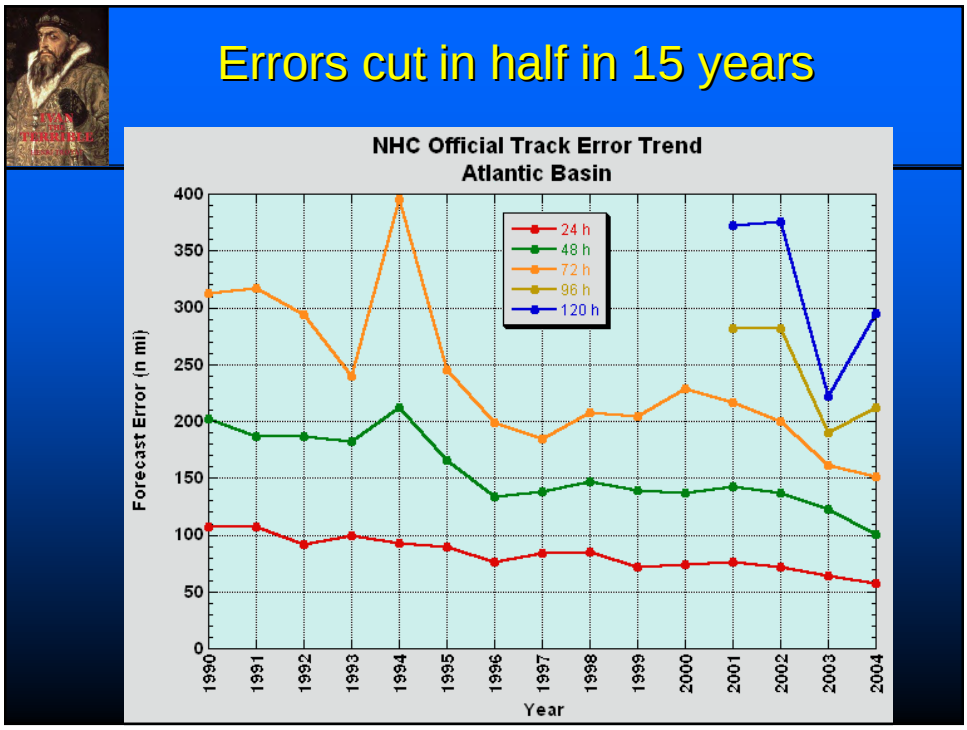
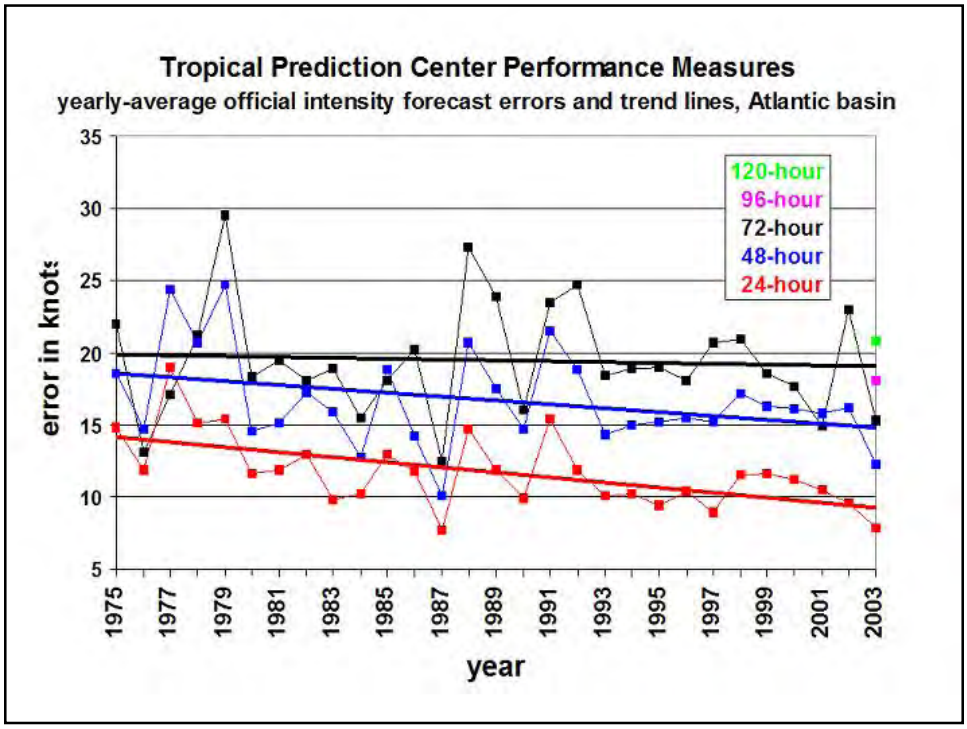
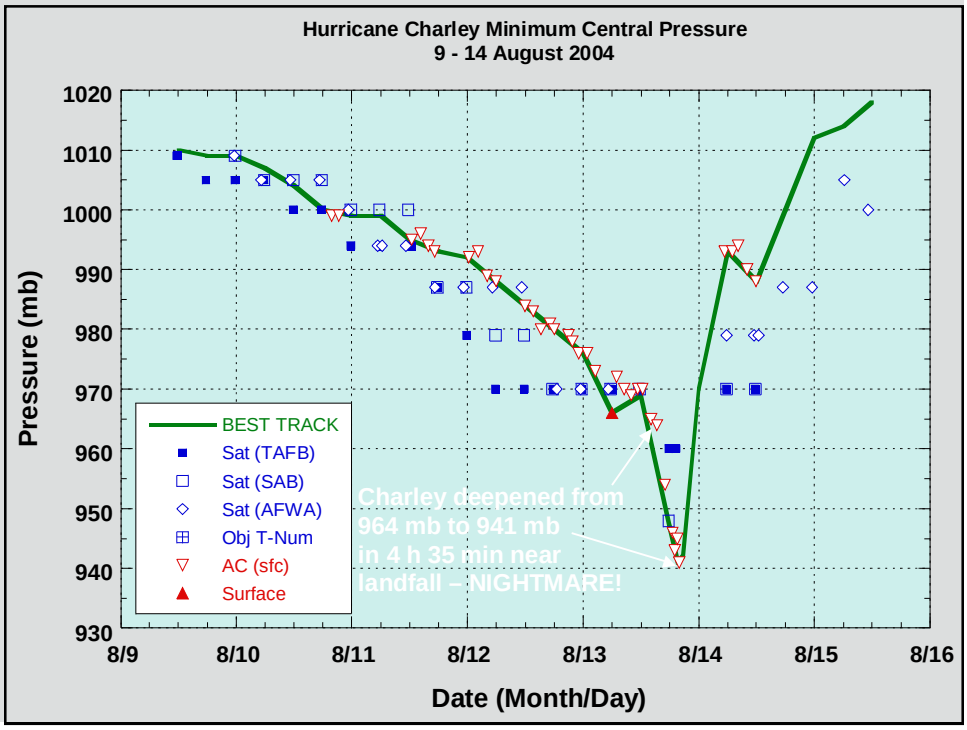
2002

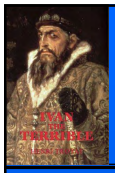

ATLANTIC MAJOR HURRICANES (1944-2004)
OF MAJOR HURRICANES
MAJOR HURRICANES
5 YEAR AVERAGE
0
1
2
3
4
5
6
7
8
9
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000


Tropical Prediction Center Performance Measures
yearly-average official track forecast errors and trend lines, Atlantic basin
error in n. mi
year
120-hour
96-hour
72-hour
48-hour
24-hour
700
600
500
400
300
200
100
0
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002


Errors cut in half in 15 years
NHC Official Track Error Trend
Atlantic Basin
Forecast Error (n mi)
Year
24 h
48 h
72 h
96 h
120 h
400
350
300
250
200
150
100
50
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004


Tropical Prediction Center Performance Measures
yearly-average official intensity forecast errors and trend lines, Atlantic basin
error in knots
year
120-hour
96-hour
72-hour
48-hour
24-hour
35
30
25
20
15
10
5
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003


Hurricane Charley Minimum Central Pressure
9 - 14 August 2004
Pressure (mb)
Date (Month/Day)
BEST TRACK
Sat (TAFB)
Sat (SAB)
Sat (AFWA)
Obj T-Num
AC (sfc)
Surface
Charley deepened from
964 mb to 941 mb
in 4 h 35 min near
landfall – NIGHTMARE!
1020
1010
1000
990
980
970
960
950
940
930
8/9
8/10
8/11
8/12
8/13
8/14
8/15
8/16



FORECAST IMPROVEMENT

- **Better Observations**
- **Improved Computer Models**

How Do We Track A Hurricane?

- ***Satellite Imagery***

  GOES East and Goes West
  Visual, IR, WV
  Every 15-30 minutes (rapid update for research)
  Used to determine location, motion, and intensity

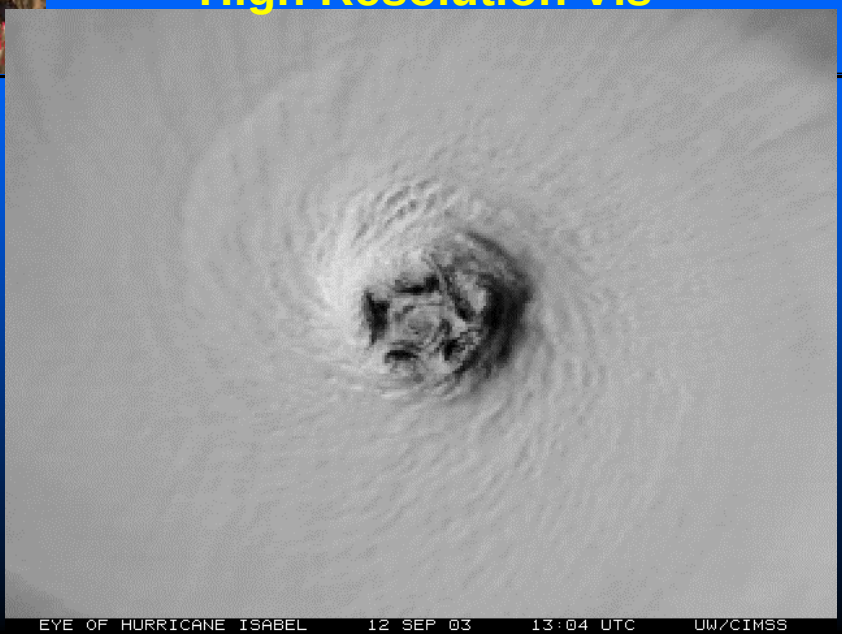
- ***Aircraft Reconnaissance***

  USAF C-130 - Primary Mission Operations
  NOAA P-3 - Primary Mission Research
  NOAA G-IV – High Altitude Operations
  More accurate than satellite

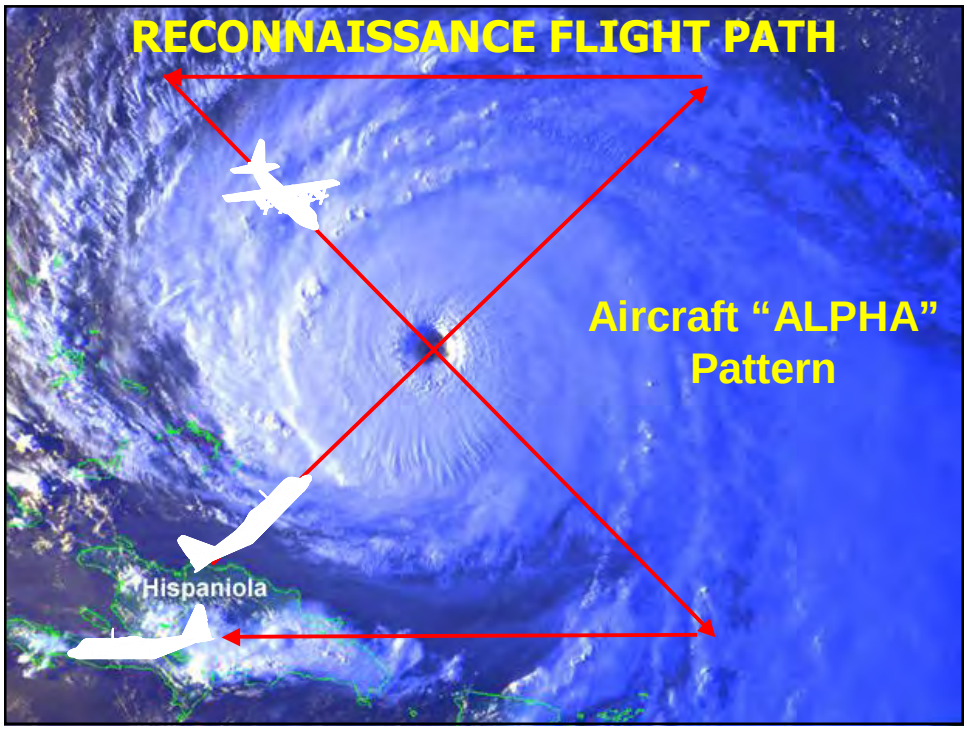
- ***Doppler Radar***

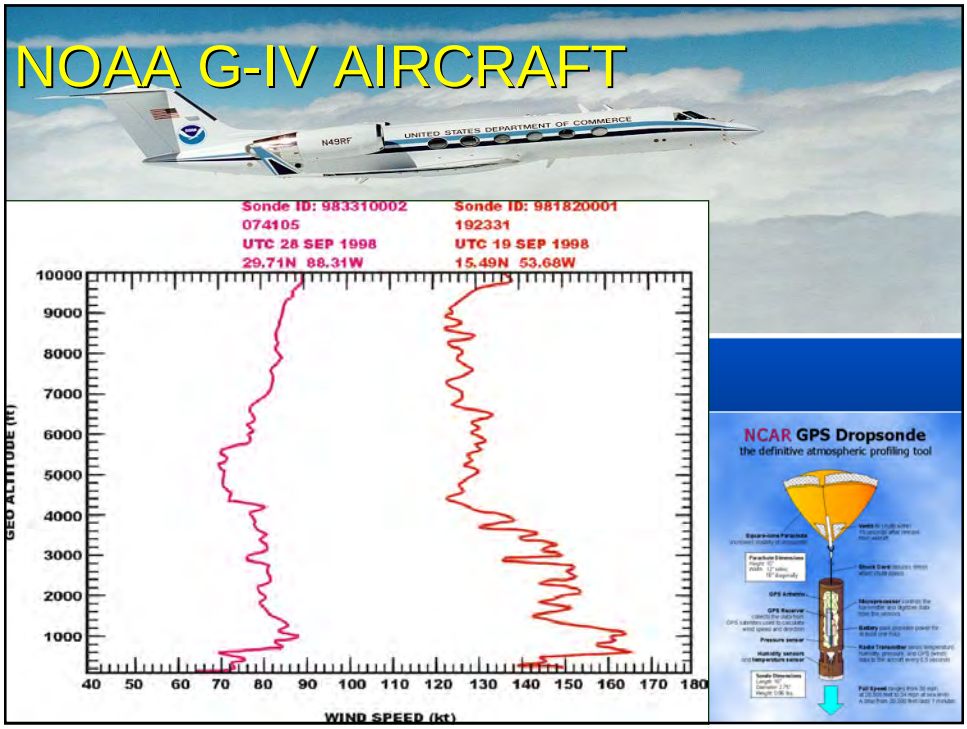
  250 nm range for reflectivity tracking
  125 nm range for Doppler velocity estimates
  Location, wind, motion, rainfall estimates and tornado detection

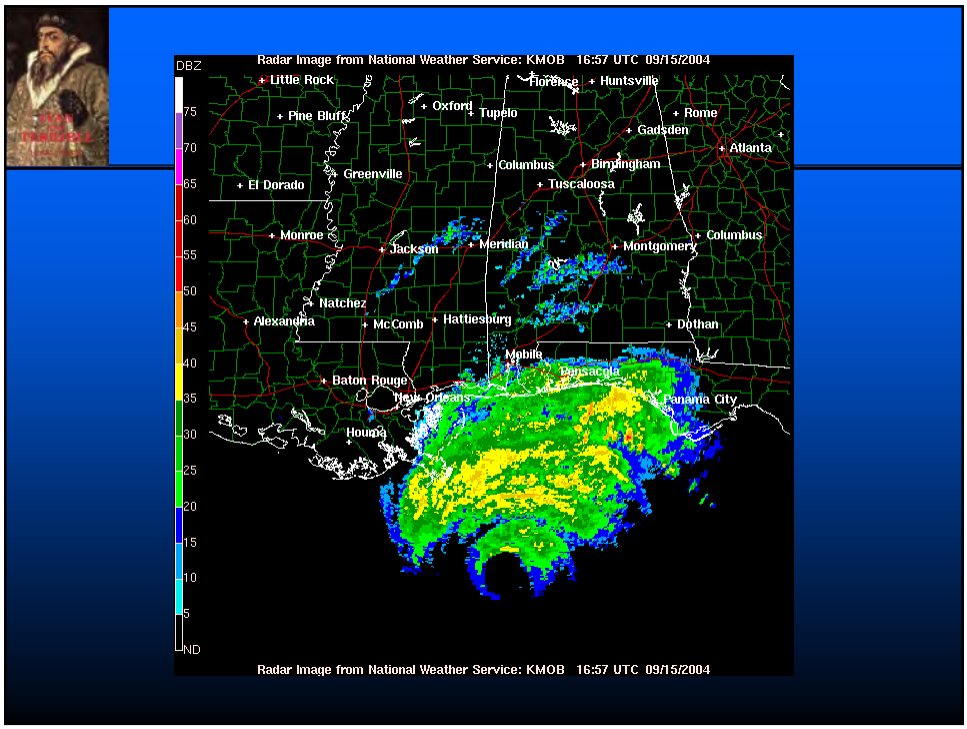
High Resolution Vis

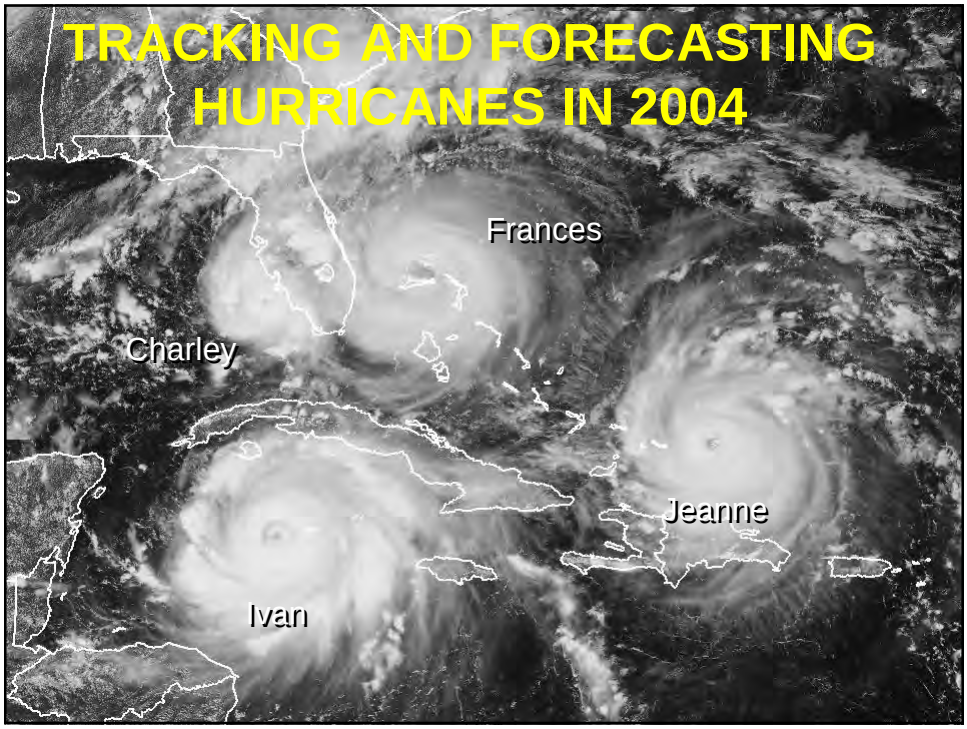


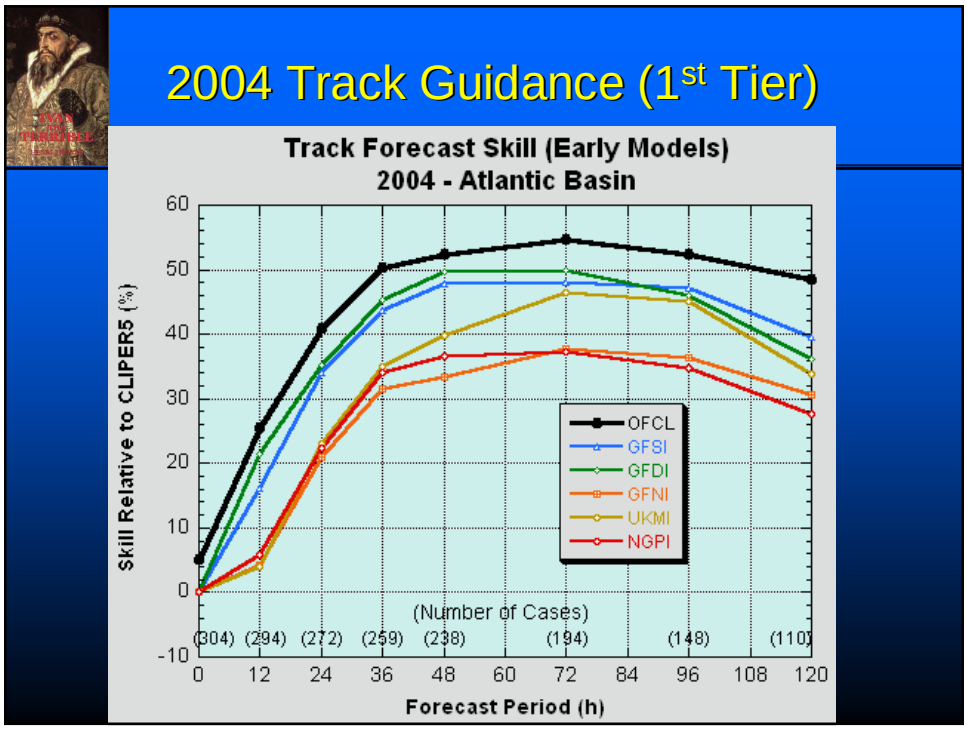
RECONNAISSANCE FLIGHT PATH



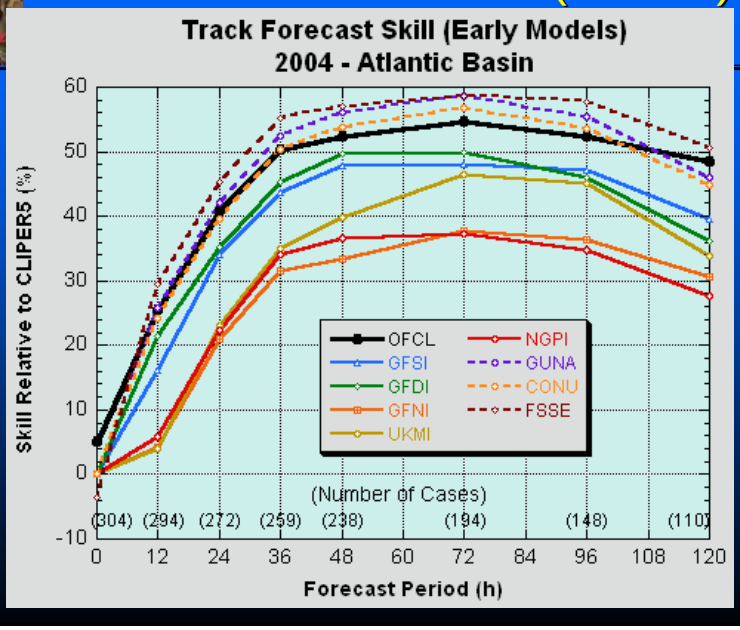

NOAA G-IV AIRCRAFT
UNITED STATES DEPARTMENT OF COMMERCE
N49RF
Sonde ID: 983310002
074105
UTC 28 SEP 1998
29.71N 88.31W
Sonde ID: 981820001
192331
UTC 19 SEP 1998
15.49N 53.68W
GEO ALTITUDE (ft)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
WIND SPEED (kt)
NCAR GPS Dropsonde
the definitive atmospheric profiling tool


Radar Image from National Weather Service: KMOB 16:57 UTC 09/15/2004
DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
ND
Little Rock
Pine Bluff
Oxford
Tupelo
Florence
Huntsville
Rome
Gadsden
Atlanta
Columbus
Birmingham
Tuscaloosa
Greenville
El Dorado
Monroe
Jackson
Meridian
Montgomery
Columbus
Natchez
Alexandria
McComb
Hattiesburg
Dothan
Mobile
Pensacola
Baton Rouge
New Orleans
Panama City
Houma
Radar Image from National Weather Service: KMOB 16:57 UTC 09/15/2004

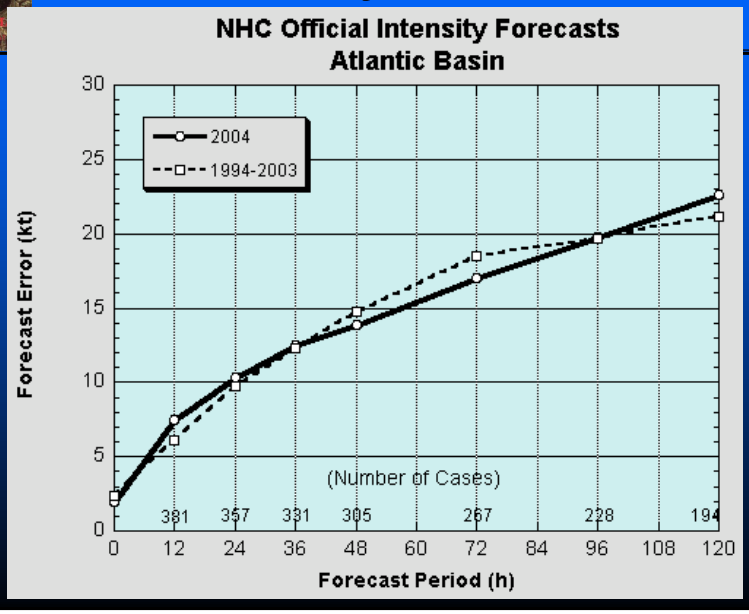

TRACKING AND FORECASTING HURRICANES IN 2004
Frances
Charley
Jeanne
Ivan

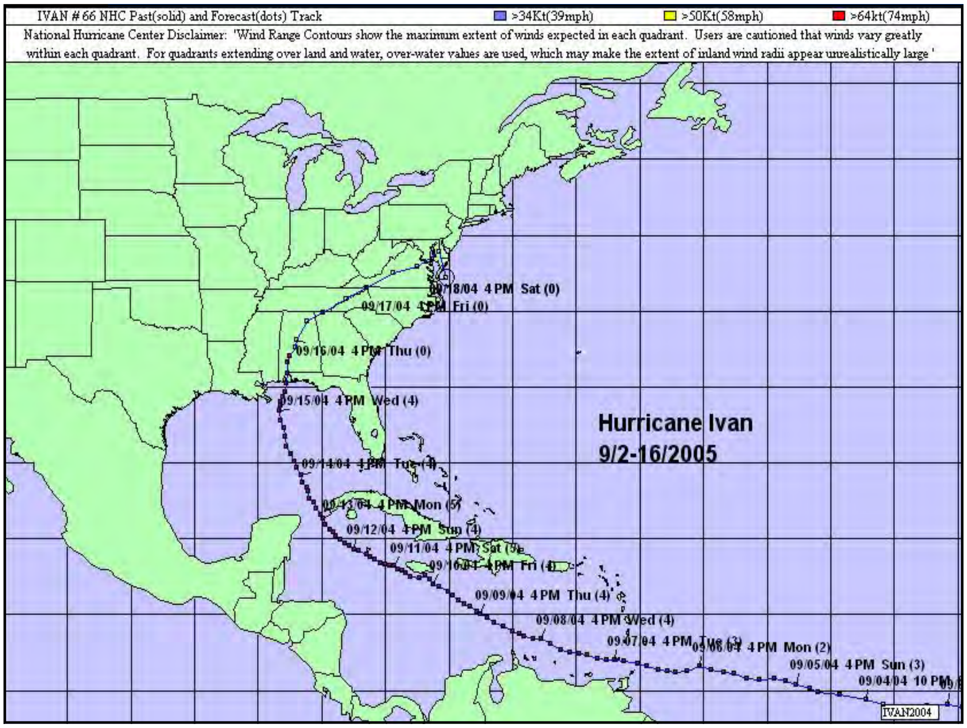

2004 Track Guidance (1st Tier)
Track Forecast Skill (Early Models)
2004 - Atlantic Basin
Skill Relative to CLIPER5 (%)
60
50
40
30
20
10
0
-10
OFCL
GFSI
GFDI
GFNI
UKMI
NGPI
(Number of Cases)
(304) (294) (272) (259) (238) (194) (148) (110)
0 12 24 36 48 60 72 84 96 108 120
Forecast Period (h)

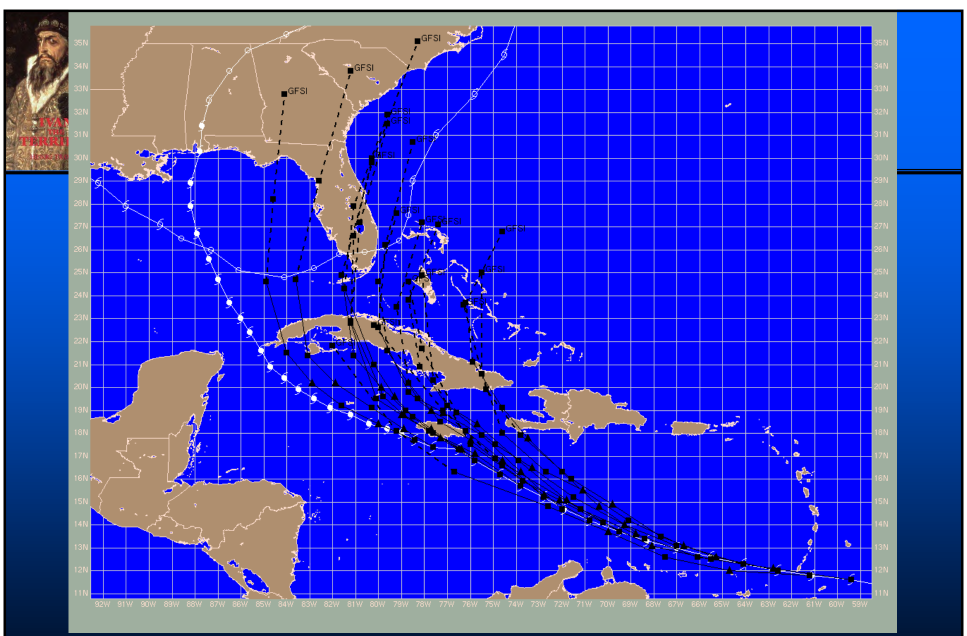
2004 Track Guidance (1st Tier)



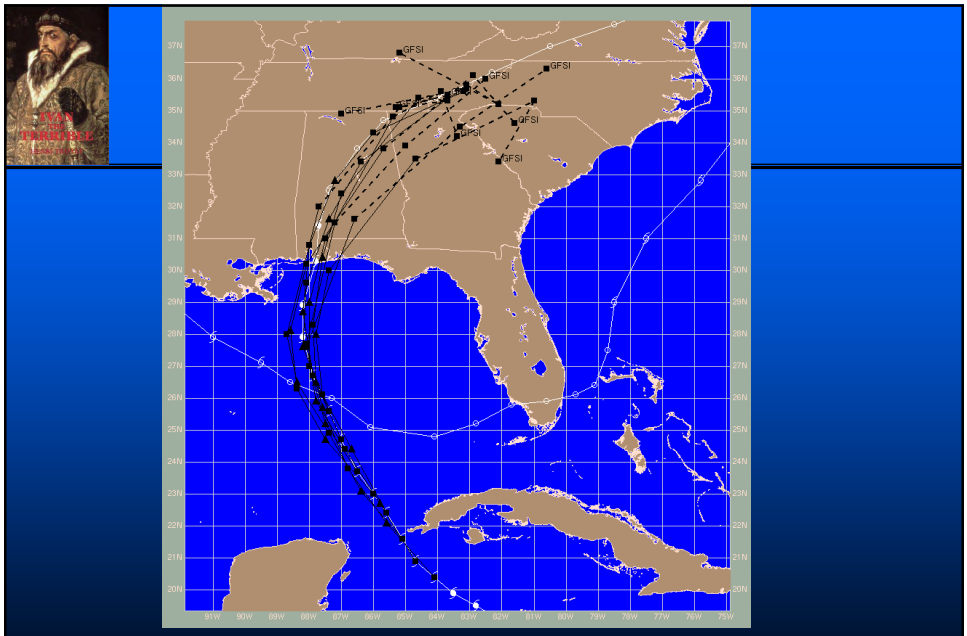
Intensity Forecasts







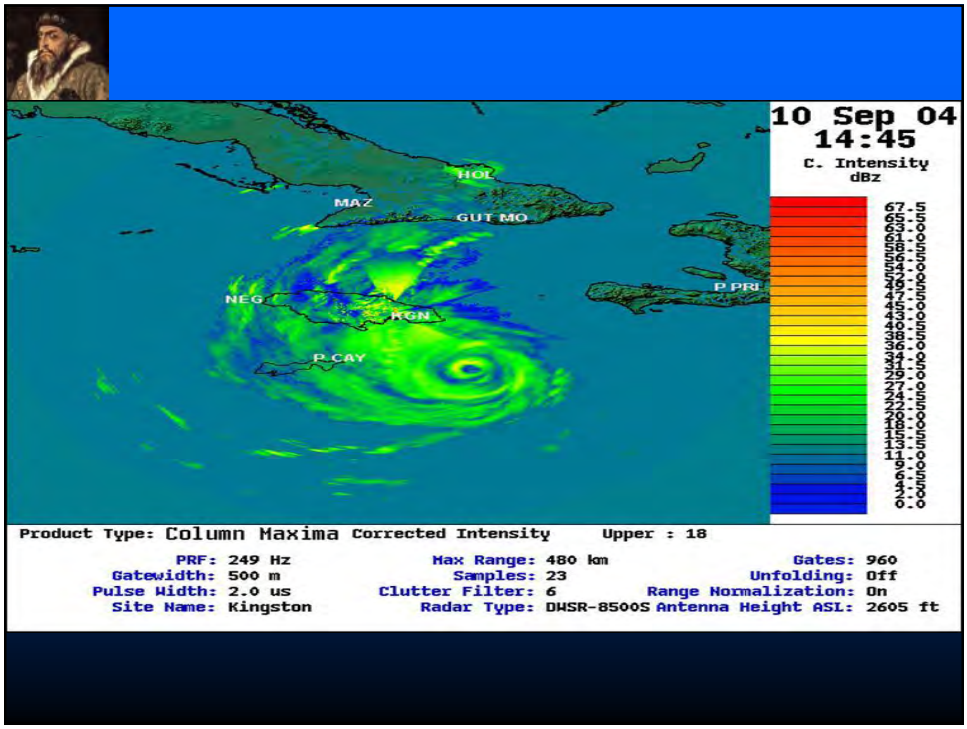
GFS TRACK FORECASTS FOR IVAN FROM 9/7/04 12Z – 9/11/04 12Z HAD A SIGNIFICANT RIGHT BIAS.

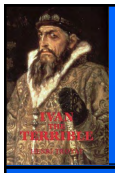


GFS TRACK FORECASTS FOR IVAN FROM 9/13/04 12Z – 9/15/04 12Z WERE EXCELLENT IN SPECIFYING IVAN'S LANDFALL LOCATION ON GULF COAST.

IVAN CHARACTERISTICS

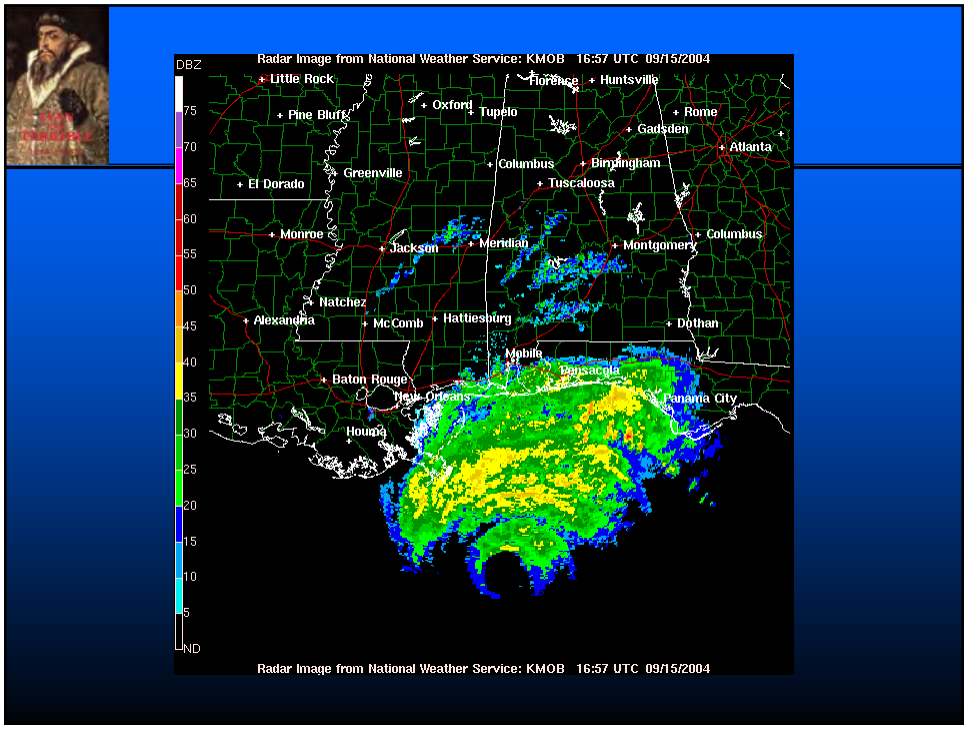
- Typical Cape Verde Storm
- Southern Most Major Hurricane
- Reached Category 5 Three Different Times
- Was a Category 5 for over 30 consecutive hours.
- Weakened and made landfall as Cat 3

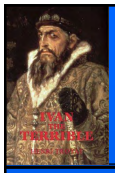




IVAN TRACK FORECAST ERRORS

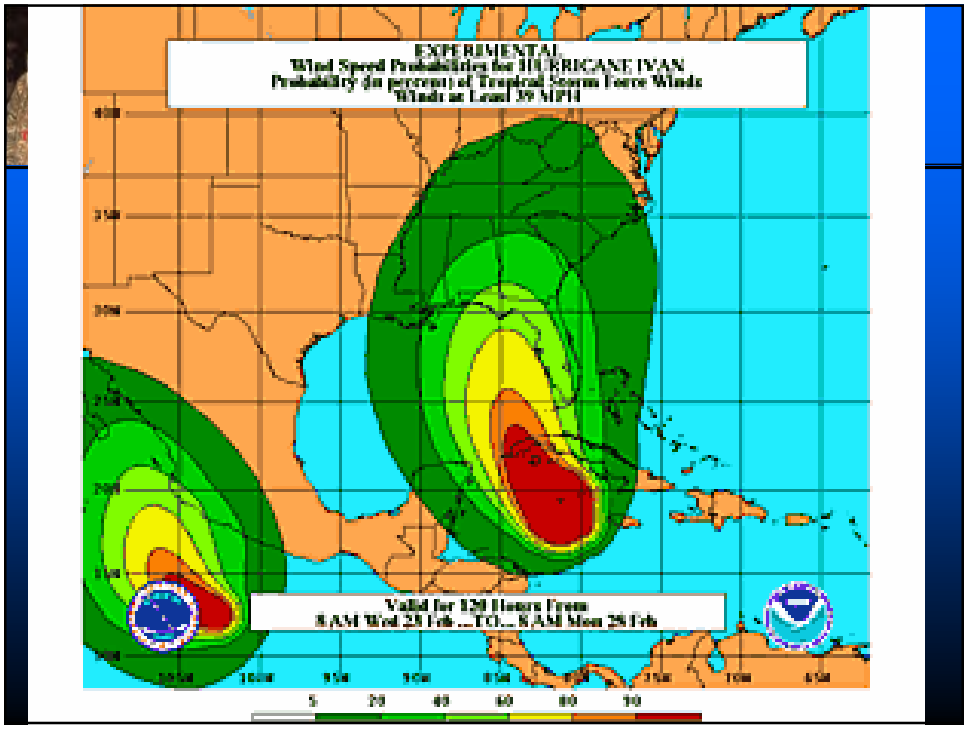
# HOURS	NHC	FSSE	10 YR AV
12	24	21	44
24	47	38	78
36	79	58	112
48	108	81	146
72	161	126	217
96	222	171	248
120	289	199	319

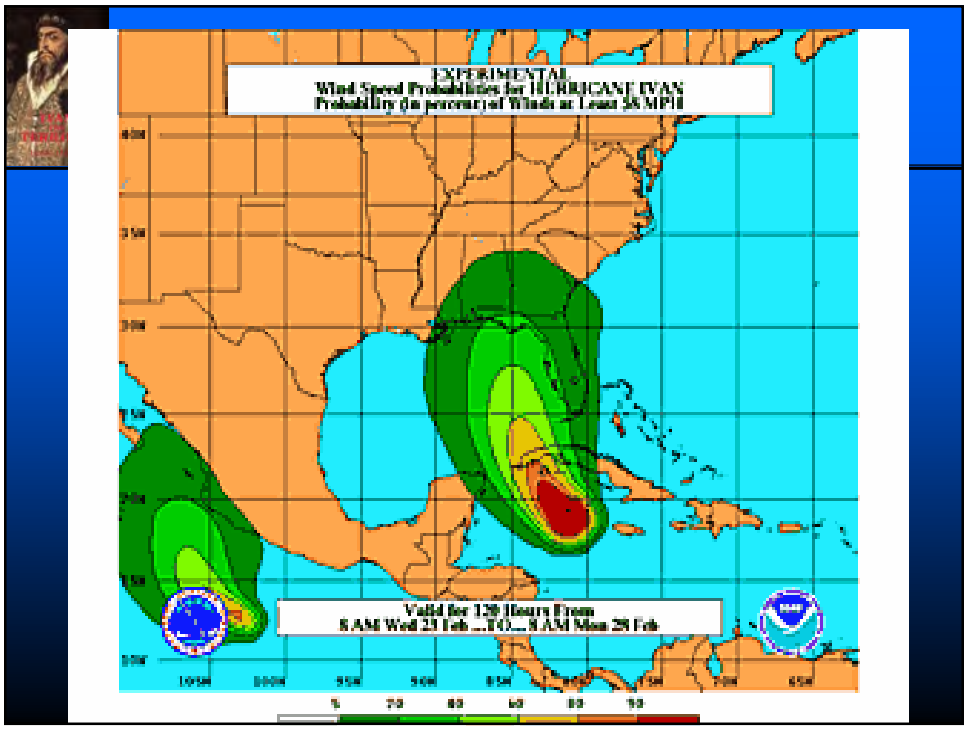


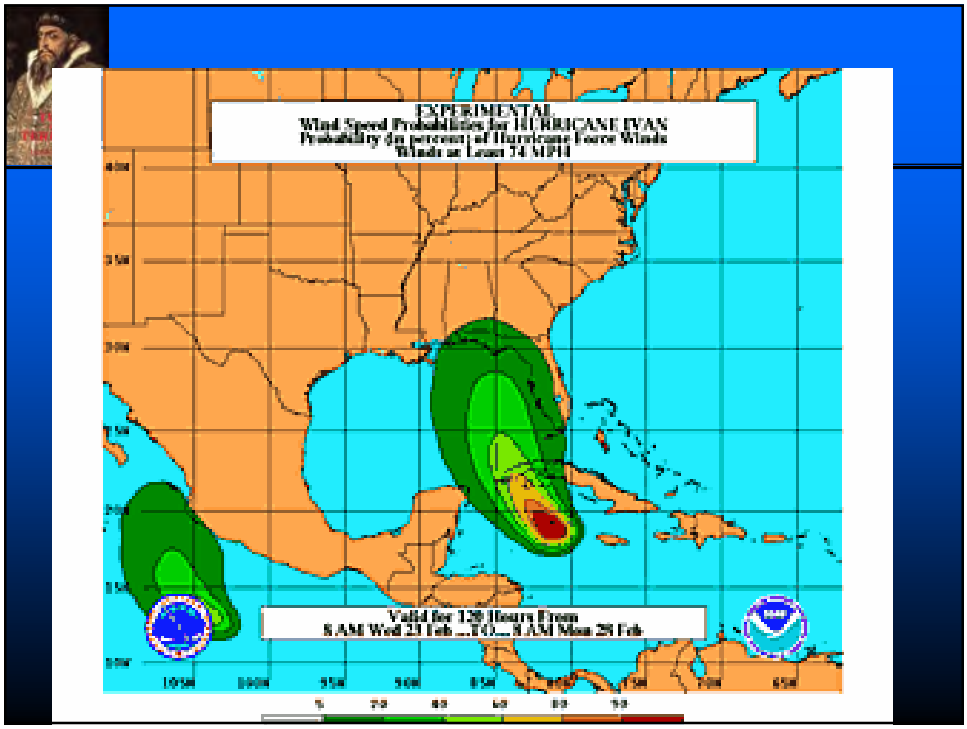


WIND PROBABILITY PRODUCT

- Experimental Product in 2005
- Available on NHC Homepage
- Graphical and Text
- Could become Operational in 2006


EXPERIMENTAL
Wind Speed Probabilities for HURRICANE IVAN
Probability (in percent) of Tropical Storm Force Winds
Winds at Least 39 MPH
Valid for 120 Hours From
8AM Wed 23 Feb ...TO... 8AM Mon 28 Feb


EXPERIMENTAL
Wind Speed Probabilities for HURRICANE IVAN
Probability (in percent) of Winds at Least 58 MPH
Valid for 120 Hours From
8AM Wed 23 Feb ...TO... 8AM Mon 28 Feb



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